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CHEMISTRY.—*On the equation for the reaction between invertase and sucrose.*[1] JOSEPH BERKSON and FRANKLIN HOLLANDER, Institute for Biological Research, Johns Hopkins University, and the Biological Laboratory, Cold Spring Harbor, Long Island, New York. (Communicated by RAYMOND PEARL.)

The equational representation of the reaction between enzyme and subtrate is still a problem requiring definitive solution. Among the many forms of mathematical function that have been attempted, none has as yet been applied to a sufficient variety of conditions to merit a good claim to generality, and furthermore most have suffered from an abundance of statistical constants that have rendered their value dubious. Under the circumstances any indication that a satisfactory function has been found seems exceedingly worth probing. Berkson and Flexner (1) have proposed a form of equation which they tested exhaustively for the particular case of gelatin and pancreatin with high success, and presented a certain amount of evidence that the general equation is applicable to other enzymes and subtrates as well. In this paper we wish to investigate its applicability to a case for which they did not present any results; the splitting of sucrose by invertase.

When the hydrolysis of sucrose is followed in time by the polariscopic method, and the percent of sugar estimated from the angle of rotation in the usual way, the function takes the following form

$$p' = \frac{K}{1 + Ce^{rt}} \qquad (1)$$

This may also be written

$$t = \frac{1}{r} \ln \frac{K - p'}{p'} - \ln C \qquad (1a)$$

[1] Received February 24, 1930.

in which

p' is the percentage of sucrose remaining unhydrolized.

t is the time after the beginning of the reaction when p′ is observed.

$C = \frac{K - 100}{100}$

K is a constant representing the asymptotic limits of the function.

r is a rate parameter which is characteristic of any particular series of observations.

e is the Napierian base.

For the cases to be investigated K can be taken as twice the initial value of p′, and we have resulting the simple form (2)

$$p' = \frac{200}{1 - e^{rt}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

We will not here enter into any discussion of the equation *per se*, our immediate problem being only its validity as a quantitative description of the reactions to be studied, and since also this ground has been covered elsewhere (1), (2). But it is appropriate to note that there is only one parameter to be determined from the observations, i.e., the rate parameter r, so that the number of "arbitrary" statistical constants is reduced to an absolute minimum.

For any test of the equation to be critical, it is essential that a broad variety of experimental conditions be included, and that for each condition a representative range of the variables be comprehended. Experiments directed to this end seemed indicated, but in examining the literature we found in the published data of Nelson and his associates a series for yeast invertase that would serve the immediate purposes in hand about as well as any which we could ourselves produce. Accordingly, it was decided to use these as the basis of our investigation and our plan is to give, summarized, the results of a systematic application of the equation to them.

The method of procedure in each instance which we will examine will be uniform as follows. From the observations as recorded, log. $\frac{200 - p'}{p'}$ will be evaluated for each observed value of p′ and this plotted *vs.* the corresponding value of t. A straight line fitted to these points has for its slope r log. e and from this r is determined as ex-

plained by Reed and Berkson (3). The parameter so evaluated will be written into equation (2) and the theoretical value of p' calculated for each value of t at which an observation was recorded. The goodness of fit will be expressed as the standard deviation, i.e., the root mean square of the deviations of calculated from observed values, and also as the coefficient of variation, i.e., the ratio of the *s.d.* to the mean p'.

I. A TYPICAL FIT FOR A USUAL REACTION

The fit to a usual case taken from Nelson and Hitchcock (4) is presented in detail in Table 1 and Figures 1 and 2.

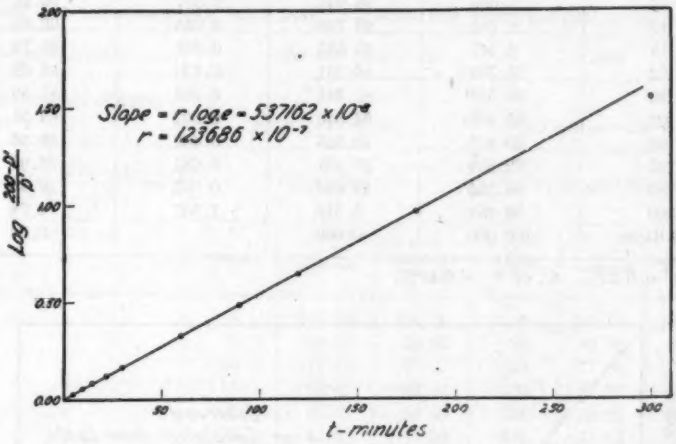

Fig. 1. Log. $\frac{200 - p'}{p'}$ vs. t, from Table 1

The equation for example I becomes (3)

$$p' = \frac{200}{1 + e^{0.0123686\,t}} \qquad (3)$$

As can be seen from Table 1 and the corresponding graphs there is a satisfactory agreement between the observed values of p′ and those calculated from the equation. Similar calculations for other experiments some of which are included in subsequent sections of this paper all show a comparably satisfactory agreement.

II. VARIATION IN ENZYME CONCENTRATION

For a study of the influence of enzyme concentration on the applicability of equation (2), it is obviously sufficient to compare but two

TABLE 1. A USUAL YEAST INVERTASE REACTION

NELSON AND HITCHCOCK (4), PAGE 2633. EXPERIMENTS B9 AND B10.

Sucrose concentration, 10 gm. per 100 c.c. Invertase 1, concentration 6.080 c.c. per 100 c.c. Temperature 25°C.

t min.	p inverted (means) %	p' left observed %	$\log \frac{200 - p'}{p'}$	p' calculated from (3) %
0	0.000	100.000	0.000	100.00
5	3.056	96.944	0.027	96.91
10	6.291	93.709	0.055	93.82
15	9.347	90.653	0.081	90.75
22	13.709	86.291	0.120	86.48
30	18.516	81.484	0.163	81.66
60	35.460	64.540	0.322	64.51
90	50.415	49.585	0.482	49.46
120	62.819	37.181	0.641	36.96
180	80.356	19.644	0.963	19.48
300	94.481	5.519	1.547	4.78
2–4 days	100.000	0.000		0.00

S. D. = 0.25%. C. of V. = 0.41%.

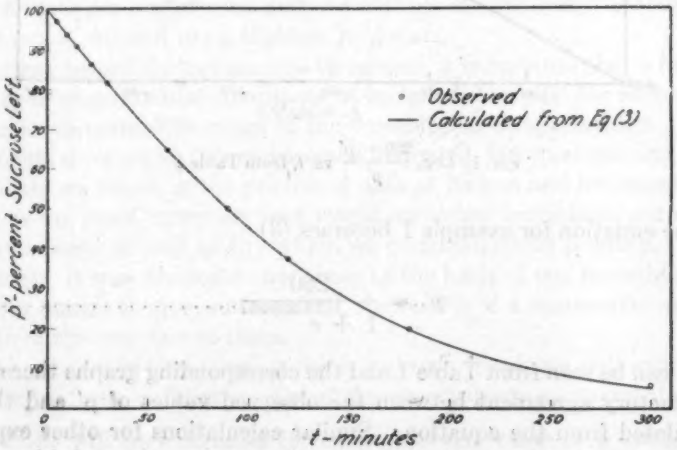

Fig. 2. Graphical presentation of fit for example I

typical experiments, provided these two cases differ sufficiently to include a wide range in concentration. In experiments B60, 61 and

B62 of Nelson and Hitchcock (4), two series are available in which the concentrations are 6 and 0.5 cc. per 100 cc. respectively. This is as great a variation in this factor as can be found in the literature. That equation (2) fits both of these is apparent from Table 2. The relation between r and concentration will be discussed below.

III. VARIATION IN SUBTRATE CONCENTRATION

Inclusion of the initial sucrose concentration as a variable has been a major difficulty in every effort to obtain a universal equation de-

TABLE 2. EXTREMES OF INVERTASE CONCENTRATION

NELSON AND HITCHCOCK (4), PAGE 2641. SUCROSE AND TEMPERATURE AS IN TABLE 1

Experiment number.....	B60 and B61			B62		
Concentration of invertase 8.....	6 c.c. per 100 c.c.			0.5 c.c. per 100 c.c.		
r, from log. $\frac{200-p'}{p'}$ vs. t	0.0456796			0.00371204		
	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)
	0	100.00	100.00	0	100.00	100.00
	5	88.25	88.62	60	88.55	88.91
	10	77.15	77.54	120	77.69	78.09
	15	66.82	67.01	180	67.60	67.78
	21	55.37	55.39	252	56.32	56.37
	28	43.62	43.53	336	44.93	44.64
	37	31.16	31.13	444	32.70	32.27
	52	16.74	17.00	624	18.46	17.96
	70	7.89	7.84	840	9.20	8.47
	1–7 days	0.00	0.00	11 days	0.00	0.00
S. D.....		0.20%			0.37%	
C. of V.....		0.41%			0.75%	

scribing the hydrolysis of sucrose by invertase. In order to test the applicability of the logistic function in this respect a series of experiments were chosen from the investigation of Nelson and Vosburgh (5) in which the substrate concentration was varied from 0.4 g. to 20 g. per 100 cc. of solution. The fits of equation (2) to these experiments are given in Table 3.

The fits for these experiments of Nelson and Vosburgh are seen to be

TABLE 3. VARIATION IN SUCROSE CONCENTRATION

NELSON AND VOSBURGH (5) PAGES 796–7

Experiment number....	31b			30b			29c			28b			27b			26			25		
Sucrose concentration..	0.4 gm. per 100 c.c.			1 gm. per 100 c.c.			2 gm. per 100 c.c.			4 gm. per 100 c.c.			5 gm. per 100 c.c.			10 gm. per 100 c.c.			20 gm. per 100 c.c.		
r, from log. $\frac{200-p'}{p'}$ vs. t	0.0152546			0.0108922			0.00777122			0.00406339			0.00345388			0.00167593			0.000713058		
	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)
	0	100.0	100.0	0	100.0	100.0	0	100.0	100.0	0	100.0	100.0	0	100.0	100.0	0	100.0	100.0	0	100.0	100.0
	15	89.1	88.6	20	88.8	89.1	40	84.6	84.6	45	91.2	90.9	90	84.5	84.6	90	92.4	92.4	240	91.4	91.5
	25	80.6	81.2	40	78.9	78.6	60	76.9	77.1	90	81.7	81.9	135	77.5	77.1	180	85.0	85.0	420	85.1	85.1
	35	74.2	73.9	50	73.8	73.4	75	71.5	71.7	120	76.0	76.1	150	75.3	74.7	240	80.4	80.2	540	80.9	81.0
	40	70.6	70.4	∞	0.0	0.0	85	68.5	68.1	130	74.3	74.2	165	72.9	72.3	300	75.6	75.4	660	77.1	76.9
	∞	0.0	0.0				∞	0.0	0.0	140	72.4	72.3	∞	0.0	0.0	360	71.6	70.7	780	73.4	72.9
										∞	0.0	0.0				∞	0.0	0.0	∞	0.0	0.0
S. D.....	0.33%			0.28%			0.19%			0.16%			0.40%			0.34%			0.23%		
C. of V.....	0.48%			0.41%			0.28%			0.23%			0.58%			0.47%			0.31%		

good and, considering the size of the standard deviation, comparable with experiments utilizing 10% sucrose. However, while the range in variation of substrate concentration is fairly wide, the individual experiments are carried only to a point of about 30% hydrolysis. It is desirable to test the equation for comparable cases in which the hydrolysis has continued more nearly to completion. For this purpose three experiments in the series of Nelson and Vosburgh (5) in which the observations were continued up to within 95% hydrolysis are included here and given in Table 4.

TABLE 4. VARIATION IN SUCROSE CONCENTRATION

NELSON AND VOSBURGH (5), PAGE 794

Experiment number.....	3			8			13		
Sucrose concentration...	5 gm. per 100 c.c.			10 gm. per 100 c.c.			20 gm. per 100 c.c.		
r, from log. $\frac{200 - p'}{p'}$ vs. t	0.0162790			0.0036111			0.00347600		
	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)
	0	100.00	100.00	0	100.00	100.00	0	100.00	100.00
	12	89.95	90.26	20	91.69	91.71	55	90.28	90.47
	24	79.90	80.71	45	81.31	81.51	125	78.16	78.60
	51	60.18	60.72	105	58.83	58.92	250	58.49	59.08
	85	40.07	40.08	175	37.89	37.84	392	40.20	40.75
	130	21.65	21.50	265	19.91	19.89	636	19.95	19.75
	234	4.90	4.34	450	5.15	4.63	1350	3.92[a]	1.81
	∞	0.00	0.00	∞	0.00	0.00	∞	0.00	0.00
S. D.....	0.42%			0.20%			0.36%		
C. of V.....	0.85%			0.41%			0.66%		

[a] Omitted in calculation of S. D.

IV. VARIATION IN TEMPERATURE

Nelson and Hitchcock (4) give data from the experiments of Vosburgh and Nelson in which the temparature was varied. The fits of equation (2) to these are presented in Table 5.

V. A SPECIAL CASE OF "ABNORMAL" INVERTASE

Nelson and Hitchcock (4) give data for reactions with invertase which they call "abnormal" by virtue of a criterion employed by them. The fit of equation (2) to one of these is given in Table 6.

TABLE 5. VARIATION IN TEMPERATURE

NELSON AND HITCHCOCK (4), PAGE 2642. SUCROSE CONCENTRATION, 10 GM. PER 100 C.C. INVERTASE 8, CONCENTRATION, 1 C.C. PER 100 C.C.

Experiment number.....	11B			15B			1B			5B			7B		
Temperature.....	15°C.			20°C.			25°C.			30°C.			35°C.		
r, from log. $\frac{200-p'}{p'}$ vs. t	0.00446347			0.00607385			0.00809619			0.0103361			0.0128674		
	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)
	0	100.00	100.00	0	100.00	100.00	0	100.00	100.00	0	100.00	100.00	0	100.00	100.00
	63	85.46	86.03	16	94.96	95.14	15	93.83	93.94	9	95.07	95.35	8	94.50	94.86
	110	75.61	75.93	38	88.13	88.51	36	85.40	85.53	29	84.93	85.12	24	84.24	84.68
	162	65.28	65.34	65	80.18	80.51	63	75.20	75.04	50	74.78	74.72	42	73.41	73.62
	250	49.52	49.36	120	65.10	65.09	105	60.30	59.88	71	64.95	64.87	60	63.09	63.21
	350	34.96	34.67	155	56.32	56.12	165	42.61	41.64	107	50.21	49.73	90	47.89	47.80
	441	24.93	24.51	190	48.60	47.95	235	24.76	25.96	153	34.66	34.12	120	35.37	35.19
	586	14.12	3.62	254	36.08	35.23	360	11.16	10.29	190	24.93	24.61	155	23.98	23.96
	∞	0.00	0.00	320	25.82	25.05	∞	0.00	0.00	246	15.07	14.58	195	15.07	15.07
				420	15.13	14.47				∞	0.00	0.00	∞	0.00	0.00
				∞	0.00	0.00									
S. D.....	0.33%			0.48%			0.61%			0.31%			0.21%		
C. of V.....	0.66%			0.86%			1.12%			0.58%			0.38%		

The sample of invertase used in the above experiment was one which Nelson and Hollander (7) found to undergo destruction during the course of the reaction. It is to be noted that the standard deviation of observed values of p' from those calculated from (2) is in this instance significantly greater than in the typical case as exemplified in Table 2. Other experiments with this sample of invertase are shown in Table 8.

The survey presented above is taken to demonstrate that an equation of form (2) gives a good quantitative description of the course of reaction between sucrose and yeast invertase. The deviations of the

TABLE 6. A CASE OF "ABNORMAL" INVERTASE

NELSON AND HITCHCOCK (4) PAGE 2643. EXPERIMENTS B12 – 15. SUCROSE AND TEMPERATURE AS IN TABLE 1

Invertase 3, conc. 1.905 c.c. per 100 c.c. r, from log. $\frac{200 - p'}{p'}$ vs. $t = 0.0120745$

t min.	p' % observed	p' % calculated from (2)
0	100.00	100.00
5	96.80	96.98
10	93.65	93.77
15	90.56	90.97
22	86.35	86.79
30	81.54	82.08
60	65.04	65.28
90	50.62	50.45
120	38.52	38.03
180	21.19	20.43
300	6.42	5.20
	0.00	0.00

S. D. = 0.51%. C. of V. = 0.85%.

quantities observed from those estimated by it are small in all cases, small enought to warrant the conclusion that basically the reaction follows this equation. However, there is in the deviations a feature calling for further comment. Whereas they are nowhere large, there is in every case a notable progression in their character. This takes such a form that if the equation be fitted to the early observations, the later observations expressed as per cent substrate left tend to overshoot the estimates made from the equation. The deviations at first increase and then decline, the observed and calculated quantities

approaching each other as the reaction nears completion. In all the reactions studied this characteristic can be discerned, but it is more marked in some than in others. We conclude from these facts that the equation (2) is not the completely correct one for all reactions between invertase and sucrose, but that subsidiary small corrections varying in amount with different conditions must be made to render it so. What mathematical form will best represent these corrections we are not ourselves decided. This much however may be advanced. The deviations in question are manifested in the graphs of log. $\frac{200 - p'}{p'}$ *vs.* t as a small but perceptible curvature concave towards the t axis, i.e., the slope of this function decreases as t increases. To show this we have

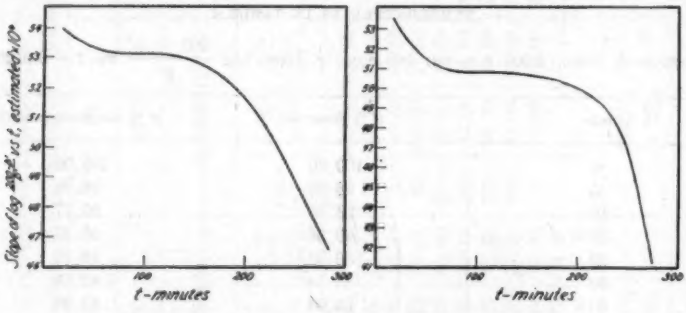

Fig. 3. Slope of log. $\frac{200 - p'}{p'}$ vs. t as estimated graphically, vs. t. Example I left, example VI right.

estimated the slope for different values of t by a graphical method and in Figure 3 the estimates so obtained are shown as smooth curves against t for the experiments of examples I and VI. Now if the logistic function (2) held strictly, these slopes should be constant, and, if they were subject only to random experimental variation, they should vary normally about some mean value. The fact that they decrease progressively may be accounted for by a progressive decrease of r. What the chemical mechanism of the reduction is, one can not say from an examination of these experimental results alone. But whatever its cause, quantitatively its effect is small as is shown by the fact that the values of p' approximate closely the values calculated from (2) which assumes r constant.

Relationship of the Rate Parameter r, and Other Variables

If equation (2) is really definitive of the reaction between yeast invertase and sucrose the one parameter in it which, by hypothesis, can change, should bear a regular relationship to conditions which affect the reaction, i.e., r should be a function of the variables which measure such conditions.

In the experiments available here it is possible to examine the relationship for concentration of enzyme, concentration of substrate, and temperature. These will be presented briefly seriatim in graphic form.

I. Concentration of Invertase

In the series of data given by Nelson and Hitchcock (4) two are available for testing the relationship of r to concentration of invertase.

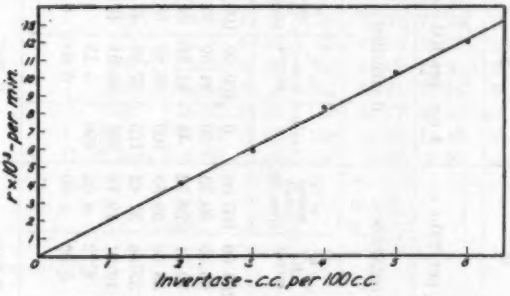

Fig. 4. r vs. concentration of invertase, from Table 7

In Tables 7 and 8 the fits of equation (2) to these data are presented in the same way as for the examples given above. In Figures 4 and 5 the r's obtained from these fits are shown plotted *vs.* the concentration of invertase.

It is seen that a relationship of constant proportionality exists between r and concentration of invertase. This is in agreement with the findings of Berkson and Flexner for other enzymes (6).

II. Concentration of Sucrose

In the experiments of Nelson and Vosburgh given in Table 4 above, the conditions were identical except for concentration of sucrose. Below in Figure 6 is shown graphically the variation of r with concentration of sucrose.

TABLE 7. VARYING CONCENTRATIONS OF INVERTASE

NELSON AND HITCHCOCK (4), PAGE 2640. SUCROSE CONCENTRATION, 10 GR. PER 100 C.C.

Experiment number.....	10			9			8			7			6		
Invertase A concentration.....	2 c.c. per 100 c.c.			3 c.c. per 100 c.c.			4 c.c. per 100 c.c.			5 c.c. per 100 c.c.			6 c.c. per 100 c.c.		
r, from log. $\frac{200 - p'}{p'}$ vs. t	0.00406339			0.00587638			0.00831901			0.0102425			0.120135		
	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)
	0	100.00	100.00	0	100.00	100.00	0	100.00	100.00	0	100.00	100.00	0	100.00	100.00
	50	89.99	89.88	33	90.43	90.33	20	91.69	91.70	22	88.92	88.78	14	91.68	91.61
	100	79.86	79.96	70	79.51	79.72	45	81.31	81.50	40	79.85	79.80	30	82.08	82.17
	221	57.91	57.89	150	58.50	58.58	105	58.83	58.90	90	56.79	56.92	70	60.15	60.27
	315	43.90	43.51	250	37.56	37.42	175	37.39	37.82	138	39.02	39.14	120	38.10	38.26
	345	39.96	39.50	376	19.91	19.78	265	19.91	19.87	215	19.70	19.91	185	19.41	19.55
	570	18.40	17.96	660	4.72	4.05	450	5.15	4.62	373	4.96	4.29	320	5.03	4.19
	1365	1.94	0.78	∞	0.00	0.00	∞	0.00	0.00	∞	0.00	0.00	∞	0.00	0.00
	∞	0.00	0.00												
S. D.....		0.46%			0.26%			0.20%			0.26%			0.31%	
C. of V.....		0.96%			0.53%			0.41%			0.54%			0.63%	

TABLE 8. VARYING CONCENTRATIONS OF INVERTASE

NELSON AND HITCHCOCK (4), PAGE 2650. SUCROSE CONCENTRATION, 10 GM. PER 100 C.C. TEMPERATURE 37°

Experiment number...	B58 and B59			B54 and B55			B56 and B57		
Invertase 3, concentration.....	0.5 c.c. per 100 c.c.			3 c.c. per 100 c.c.			6 c.c. per 100 c.c.		
r, from log. $\frac{200-p'}{p'}$ vs. t	0.00290853			0.0182852			0.0365855		
	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)	t min.	p' % observed	p' % calculated from (2)
	0	100.00	100.00	0	100.00	100.00	0	100.00	100.00
	60	90.92	91.30	10	90.56	90.88	6	88.72	89.07
	120	82.20	82.72	20	81.66	81.92	12	77.98	78.39
	195	72.05	72.38	30	73.12	73.24	18	67.95	68.21
	270	62.55	62.64	45	61.13	61.03	26	55.73	55.73
	360	52.58	51.96	70	44.09	43.51	35	43.62	43.49
	450	43.44	42.54	100	28.31	27.68	48	29.67	29.46
	540	35.67	34.43	120	20.77	20.05	65	17.03	16.97
	1101	10.92	7.82[a]	150	12.88	12.10	85	8.72	8.54
	7–12 days	0.00	0.00	∞'	0.00	0.00	∞	0.00	0.00
S. D.....	0.60%			0.45%			0.21%		
C. of V.....	1.00%			0.88%			0.44%		

[a] Omitted in calculating S. D.

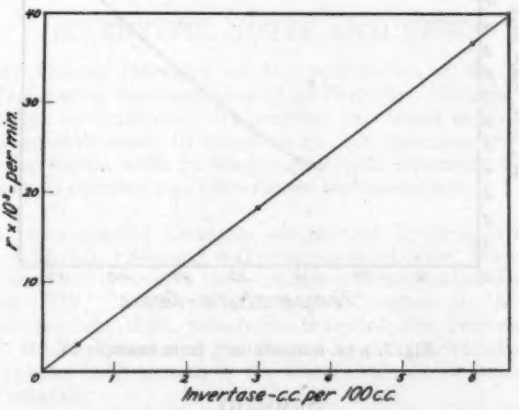

Fig. 5. r vs. concentration of invertase, from Table 8

III. TEMPERATURE

In the experiments of Nelson and Hitchcock presented in Table 5 above, temperature alone was varied. Below in Figure 7 is shown the variation or r with temperature as indicated by these experiments.

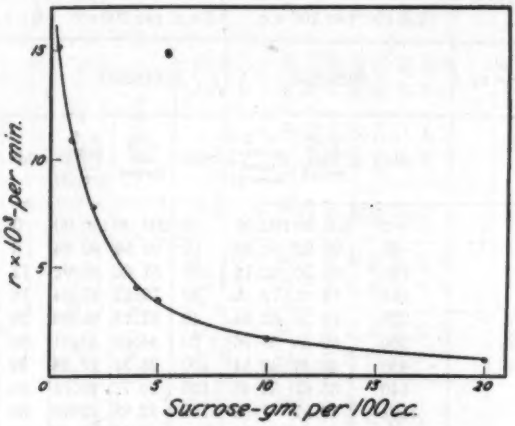

Fig. 6. r vs. concentration of sucrose, from example III

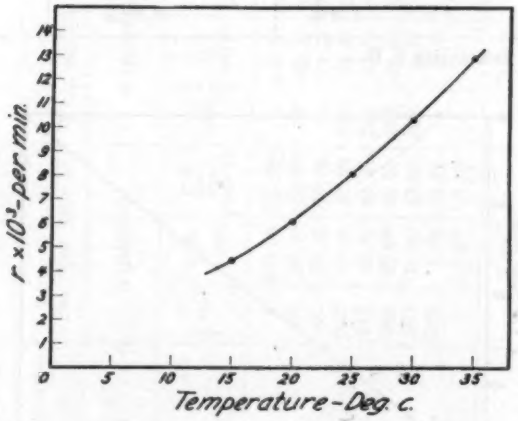

Fig. 7. r vs. temperature, from example IV

SUMMARY

1. The course of the reaction between sucrose and yeast invertase can be quantitatively described under representative conditions of

temperature, concentration of enzyme, and concentration of substrate by the function $p' = \frac{200}{1 + e^{rt}}$, where p' is the percentage of sucrose remaining unhydrolized, t is the time after the beginning of the reaction when p' is observed, r is a rate parameter which is characteristic of any particular series of observations, and e is the Napierian base.

2. The relation between the rate parameter r of the above equation and concentration of invertase is linear; the correlation line passes through the zero origin, resulting in a constancy of the ratio of concentration to r.

3. The parameter r changes regularly with concentration of sucrose; the correlation is a non-linear.

4. The parameter r changes regularly with temperature; the correlation is non-linear.

REFERENCES

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SCIENTIFIC NOTES AND NEWS

Dr. LELAND OSSIAN HOWARD, on the nomination of the Entomological Society of Washington, has been elected an Honorary Member of the WASHINGTON ACADEMY OF SCIENCES. This action was taken in recognition of his distinguished contributions to entomology, his intimate connection with scientists and scientific work in Washington, and especially for his services to the ACADEMY as member and officer since its foundation.

The First International Congress on Mental Hygiene will convene in Washington on May 5. Sessions will continue until noon, May 10. Sessions of general interest will be held in the evenings at Constitution Hall, Eighteenth and D streets, NW. The President of the Congress is Dr. WILLIAM A. WHITE, Superintendent of St. Elizabeths Hospital; the Secretary-General is CLIFFORD W. BEERS, founder of the mental-hygiene movement; Dr. FRANKWOOD E. WILLIAMS is Chairman of the Committee on Program; THOMAS W. LAMONT is Treasurer.

At the same time and place as the International Congress will be held the annual meetings of the American Psychiatric Association and the American Association for the Study of the Feebleminded.

Prof. W. G. WOOLNOUGH, Geological Adviser to the Commonwealth Government of Australia, is spending several months in the United States for the purpose of observing American methods and practices in the petroleum industry and in the administration and technique of official surveys.

An impromptu gathering of geologists at the Geological Survey on April 18 was addressed by Dr. G. S. HUME, geologist in charge of oil and gas investigations of the Geological Survey of Canada, on *The geological structure of Turner Valley, Alberta;* by E. E. L. DIXON, Esq., of the Geological Survey of Great Britain, on *Dolomitization and the development of chert;* and by Prof. W. G. WOOLNOUGH, Geological Adviser to the Commonwealth Government of Australia, on *Major structural features of Australia.*

Obituary

Commander ASAPH HALL, Corps of Professors of Mathematics, U. S. Navy, died, after a brief illness, on January 12, 1930. He was a resident of Upper Darby, Pennsylvania, at the time of his death and was engaged in post-retirement astronomical work at the Flower Observatory. Professor Hall was born in Cambridge, Massachusetts, on October 6, 1859; received his A.B. at Harvard in 1882, and his Ph.D. at Yale in 1889. Brought up amidst astronomical surroundings, he began his astronomical career as an assistant at the United States Naval Observatory, whence, after three years, he proceeded to the Yale Observatory as an assistant, and thence to the University of Michigan Observatory as Director. In 1908, he was commissioned in the Corps of Professors of Mathematics of the United States Navy and was assigned to the Naval Observatory for duty. There he took charge of the great telescope of that institution, the same instrument with which his distinguished father of the same name discovered the satellites of Mars. After his formal retirement as an officer on the active list of the Navy in 1923, he was continued on active duty at the Naval Observatory until June 30, 1929. Professor Hall was widely known for his work in connection with the satellites of the planets. His latest published work appears in Volume XII, Part I, Publications of the U. S. Naval Observatory, which contains the results of his observations on the great equatorial from 1908 to 1926.